DENTAL TOOL GUIDES

RELATED APPLICATIONS

This application is a continuation in part of USSN 10/350,288, the disclosure of which is incorporated herein by reference. This application is related to a PCT application filed on January 22, 2003, by same applicant in the Israel receiving office and having attorney docket number 368-03870, the disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

The present application relates to the guiding of tools, for example a dental drill.

BACKGROUND OF THE INVENTION

In manual applications where a high precision is required over time, it is customary to use tool guides. For example, when drilling holes in a jaw bone for tooth implants, a stent is manufactured which fits the jaw and includes one or more bores which serve to guide a drill in an exact trajectory towards the jawbone.

Tool guides are also used in brain surgery, where a sterotactic frame is mounted on a skull, imaged thereto and registered to 3D images of the brain. A trajectory into the brain is planned and the frame is set up to guide one or more tools along this trajectory. Adjustable frames are also used for other organs, such as the knee.

US patent 5,562,448, the disclosure of which is incorporated herein by reference describes a dental drill guide positioning system using one or more position sensors to determine a position of a dental drill and indicate, on an image, an expected trajectory thereof.

SUMMARY OF THE INVENTION

A broad aspect of some embodiments of the invention relates to tool guide sections which can be tracked and/or positioned relative to a base station. In an exemplary embodiment of the invention, such tracking is local and only includes determining relative positions and/or orientations of elements in the immediate vicinity of the tool guide section and the base section, for examples in a mouth.

An aspect of some embodiments of the invention relates to small and adjustable medical tool guides, for example for dental use. In an exemplary embodiment of the invention, a tool guide includes a base section for fixedly coupling to a human body portion, and an adjustable guide section which can be adjusted in at least three degrees of freedom relative to the base, after the base is coupled to the body. Optionally, the degrees of freedom include at least one position degree of freedom and at least one orientation degree of freedom.

Optionally, the guide section and/or the base section include one or more sensors which generate a signal responsive to the adjustment of the guide section. Optionally, such indication is transmitted using a wired or wireless transmitter provided in or with the tool guide.

In an exemplary embodiment of the invention, the guide section has the form of an articulating arm. Optionally, the arm is lockable in position once adjusted. Optionally the tool guide is in two separate parts where the guide section can be mounted on the base section, for example after the base section is mounted to a body and after the guide section is optionally locked in position. In an alternative embodiment, the guide section has the form of a rod extending from a box and including a tiltable tip.

In an exemplary embodiment of the invention, the tool guide is designed to have an adjustment range smaller than 2 cm in maximum extent. Optionally, the whole tool guide fits in a volume suitable for fitting in a mouth, for example, smaller than 8 cm or smaller than 5 cm in maximum extent. In one example, the guide is used as a drill guide, small enough to fit in a mouth, with the base being adapted to mount on a jaw or a tooth.

In an exemplary embodiment of the invention, the tool guide is not mechanically coupled to the base. Instead, sensors (e.g., optical sensors) on the base and/or tool guide determine their relative positions In an exemplary embodiment of the invention, the tool guide sensors are mounted on a dental tool.

A broad aspect of some embodiments of the invention relates to methods and apparatus for registering a base section to a hard tissue, such as a jawbone. In an exemplary embodiment of the invention, the base section is wholly contained in the mouth. Optionally, the base section is registered to a previous image of the hard tissue.

An aspect of some embodiments of the invention relates to a method of registering a stent to an existing image of a jaw, for example a 3D CT image data set. In an exemplary embodiment of the invention, a stent is mounted on a jawbone after the existing image is acquired. Optionally, this allows the acquisition of CT image to be made without first committing to a particular dental treatment process and/or at a different time and place. Optionally, however, the CT image is acquired with the stent attached. Then, a non-volumetric image of the stent and jawbone is acquired, for example, a surface image acquired using optical scanning or using a camera. Optionally, the stent includes one or more visible markers. A jaw bone portion of the acquired surface image is then correlated to the existing image. In an exemplary embodiment of the invention, the stent includes a mounting point for a tool guide section, which mounting point is suitable for rigid coupling of the tool guide section to the jaw

bone. In an exemplary embodiment of the invention, the tool guide section is an adjustable arm of the type described herein.

An aspect of some embodiments of the invention relates to a registerable dental stent. In an exemplary embodiment of the invention, the stent includes one or more x-ray opaque markers arranged so that the stent position and/or orientation can be seen in a 2D x-ray transmission image. Optionally, the stent is otherwise partially or completely transparent to x-rays. Optionally, the stent includes a marking which is identifiable using optical surface scanning.

In an exemplary embodiment of the invention, the stent is used to determine a depth to a mandibular canal. Optionally, the stent includes means for determining a surface geometry of underlying bone.

A broad aspect of some embodiments of the invention relates to methods of using a base section and/or a tool guide section, for example for dental applications.

An aspect of some embodiments of the invention relates to a guiding stent for dental applications in which a jaw area or tooth to be worked on is un-obscured. In one exemplary embodiment of the invention, the stent includes two opposing base sections for engaging a jaw bone on either side of the jaw and one or more bridge sections which attach the base sections while leaving a central area between the bridge sections un-obscured. A guide section is optionally and/or selectively mountable on one of the base sections so that it blocks access from at most one side of the jaw bone. In an alternative embodiment of the invention, a base section is adapted to be mounted on a tooth that is near the work area on a jaw bone and includes a cantilevered section which acts as a guide section and/or on which a guide section may be mounted.

A broad aspect of some embodiments of the invention relates to methods of adjusting and/or positioning of tool guide sections relative to base sections.

An aspect of some embodiments of the invention relates to a device for adjusting tool guides. In an exemplary embodiment of the invention, the device includes a receptacle for holding at least part of a guide section and a plurality of actuators, each adapted to affect at least one degree of freedom of the guide section. In an exemplary embodiment of the invention, the adjusting device includes a manual or automated input interface, operative to control the actuators, for example a port for an external controller or a set of dials.

In an exemplary embodiment of the invention, the adjuster device holds a base section and a guiding section of a tool guide and, by user or machine manipulation, the relative

positions and orientations of the base and guiding sections are changed. Optionally, the tool guide bends at its joints to conform to the relative positions, such that for any particular relative position, there may be more than one arm adjustment. In some implementations, this method generally depends on the number of degrees of freedom of the arm and the number of degrees of positional and orientational change the adjuster is capable of.

In an exemplary embodiment of the invention, the adjuster device includes two translation tables, each corresponding to a different point along a desired bore and also includes means for relative translation of the tables. In other embodiments of the invention various hexapod designs are used.

In an exemplary embodiment of the invention, the adjuster includes a receptacle adapted to measure a length of drill guide.

There is thus provided in accordance with an exemplary embodiment of the invention, a method of dental registration, comprising:

rigidly coupling a base element to a maxillofacial area;

inserting an object comprising at least one of a tool and a tool guide into a mouth in said maxillofacial area; and

determining a position of said object relative to said rigid element without a reference element outside of said mouth. Optionally, said base element comprises a rigid element.

In an exemplary embodiment of the invention, the method comprises acquiring a 3D radiological image of at least a part of said maxillofacial area. Optionally, the method comprises acquiring a non-volumetric image of at least a part of said dental area including at least a part of said base element. Optionally, the method comprises:

identifying at least one registration mark of said rigid element on said non-volumetric image; and

registering said image to said 3D image, thereby registering said registration mark to said area.

In an exemplary embodiment of the invention, the method comprises:

acquiring a first image of at least a part of said maxillofacial area;

acquiring a non-volumetric image of least a part of said dental area including at least a part of said base element;

identifying at least one registration mark of said rigid element on said non-volumetric image; and

registering said image to said first image, thereby registering said registration mark to said area. Optionally, said first image comprises a surface image obtained using a plurality of measurable pins which penetrate gum tissue to bone tissue.

In an exemplary embodiment of the invention, said non-volumetric image comprises a 2D transmission image.

In an exemplary embodiment of the invention, determining comprises setting a desired position, and comprising selecting a desired relative position.

In an exemplary embodiment of the invention, determining comprises measuring an existing position. Optionally, determining comprises adjusting said object to a new position responsive to said measured position.

In an exemplary embodiment of the invention, determining comprises aiming said tool using said position, at said maxillofacial area.

In an exemplary embodiment of the invention, rigidly coupling comprises inserting at least one pin into gum tissue of said maxillofacial area.

In an exemplary embodiment of the invention, rigidly coupling comprises coupling using a clamp.

In an exemplary embodiment of the invention, rigidly coupling comprises releasing said base element to elastically engage said maxillofacial area.

In an exemplary embodiment of the invention, rigidly coupling comprises attaching using at least one screw.

In an exemplary embodiment of the invention, rigidly coupling comprises attaching to a single portion of said maxillofacial area.

In an exemplary embodiment of the invention, rigidly coupling comprises attaching said rigid element to be adjacent to at least 35% of a jawbone of said maxillofacial area.

In an exemplary embodiment of the invention, rigidly coupling comprises mounting on an unpeeled gum.

In an exemplary embodiment of the invention, rigidly coupling comprises mounting on a tooth.

In an exemplary embodiment of the invention, said base element is customized for a particular maxillofacial area.

In an exemplary embodiment of the invention, base element is mass produced.

In an exemplary embodiment of the invention, acquiring a non-volumetric image comprises acquiring one or more 2D transmission X-ray image of at least part of said

maxillofacial area. Optionally, the method comprises viewing at least one opaque portion of said base element to determine an allowed drilling depth in said maxillofacial area.

In an exemplary embodiment of the invention, acquiring a non-volumetric image comprises optically scanning a surface of at least part of said maxillofacial area.

In an exemplary embodiment of the invention, acquiring a non-volumetric image comprises reconstructing a surface geometry of at least part of said maxillofacial area.

In an exemplary embodiment of the invention, acquiring a non-volumetric image comprises optically imaging at least part of said maxillofacial area.

In an exemplary embodiment of the invention, acquiring a non-volumetric image comprises ultrasonically imaging at least part of said maxillofacial area.

In an exemplary embodiment of the invention, acquiring a non-volumetric image comprises contact measurement using a plurality of measured pins that penetrate gum tissue.

In an exemplary embodiment of the invention, aiming comprises adjusting one or more joints on said tool to achieve said aiming.

In an exemplary embodiment of the invention, said aiming comprises aiming at least 2 degrees of freedom of movement and orientation.

In an exemplary embodiment of the invention, said aiming comprises aiming at least 3 degrees of freedom of movement and orientation.

In an exemplary embodiment of the invention, said aiming comprises aiming at least 5 degrees of freedom of movement and orientation.

In an exemplary embodiment of the invention, said aiming comprises adjusting a depth of penetration of said tool.

In an exemplary embodiment of the invention, said aiming comprises planning a position and orientation of a tool path of said tool and adjusting at least one of said position and orientation according to said determining position.

In an exemplary embodiment of the invention, the method comprises monitoring at least one of a position and orientation of said tool during said aiming. Optionally, said monitoring comprises displaying. Optionally, said displaying comprises displaying an expected result of using said tool. Alternatively or additionally, said displaying comprises displaying a current effect of said tool. Alternatively or additionally, said displaying comprises displaying on a radiological image. Alternatively or additionally, said displaying comprises updating said display at least once per minute. Alternatively or additionally, said displaying comprises updating said display at least once per second. Alternatively or additionally, said displaying

comprises calculating an expected layout of a dental prosthesis on a bore formed using said tool; and displaying said expected layout with said monitored position. Alternatively or additionally, said displaying comprises displaying a plurality of planned bores at different locations simultaneously.

In an exemplary embodiment of the invention, the method comprises calculating an expected layout of a dental prosthesis on a bore formed using said tool; and displaying said expected layout with said determined position.

In an exemplary embodiment of the invention, said object is already mounted on said base element during said rigidly coupling.

In an exemplary embodiment of the invention, the method comprises rigidly attaching said object on said base element after said inserting. Optionally, attaching comprises attaching to a predetermining place on said base element. Alternatively or additionally, attaching comprises attaching using an adhesive. Alternatively or additionally, attaching comprises attaching mechanically.

In an exemplary embodiment of the invention, said object comprises a dental soft tissue remover. Alternatively or additionally, said object comprises a needle. Alternatively or additionally, said object comprises a cutter. Alternatively or additionally, said object comprises a laser.

In an exemplary embodiment of the invention, determining a position comprises using a plurality of encoders embedded in said tool guide

In an exemplary embodiment of the invention, determining a position comprises using a plurality of encoders embedded in said base. Optionally, said tool guide comprises a drill guide and comprising adjusting said drill guide to have a desired position and orientation. Optionally, the method comprises attaching said adjusted drill guide to a dental area. Alternatively or additionally, the method comprises locking said adjusted drill guide to maintain its adjustment.

In an exemplary embodiment of the invention, said tool comprises a drill and comprising measuring a length of a drill burr of said drill.

In an exemplary embodiment of the invention, inserting an object comprises fabricating said object. Optionally, fabricating comprises drilling a bore in said object.

There is also provided in accordance with an exemplary embodiment of the invention, a dental tool guide base, comprising:

a structure adapted to be rigidly and removably attached to a gum-covered jaw;

at least one guide attachment point defined on said structure, which at least one guide attachment point is adapted to rigidly attach a tool guide section to said structure; and

at least one registration mark adapted to be identified relative to said structure. Optionally, said structure is elastically distortable for said attaching. Alternatively or additionally, said structure comprises at least one attachment pin adapted for attaching to a gum covered jaw. Alternatively or additionally, said structure comprises at least one attachment screw adapted for attaching to a gum covered jaw.

In an exemplary embodiment of the invention, said structure is in the form of a stent.

Optionally, said structure is adapted to be attached to a small locality of said jaw.

In an exemplary embodiment of the invention, said structure is mass-produced.

In an exemplary embodiment of the invention, said registration mark is suitable for identification by optical surface scanning method.

In an exemplary embodiment of the invention, said registration mark is suitable for identification by an optical imaging method.

In an exemplary embodiment of the invention, said registration mark is suitable for identification by two-dimensional x-ray images.

In an exemplary embodiment of the invention, said registration mark is suitable for identification by ultra-sound imaging.

In an exemplary embodiment of the invention, said attachment point is a snap-locking attachment point.

In an exemplary embodiment of the invention, said registration mark and said guide attachment points are spatially separated.

In an exemplary embodiment of the invention, said registration mark and said guide attachment points are spatially overlapping.

In an exemplary embodiment of the invention, said structure comprises two opposing panels connected by at least one bridge element. Optionally, said structure comprises two opposing panels connected by at least one bridge element. Optionally, said bridge includes an aperture for guiding a drill bore therethrough.

In an exemplary embodiment of the invention, said guide attachment point is positioned to a side of said jaw when said structure is attached to a gum-covered jaw.

In an exemplary embodiment of the invention, said structure is adapted to be attached to at least one tooth.

In an exemplary embodiment of the invention, said structure is adapted to mount on a gum.

In an exemplary embodiment of the invention, said structure is substantially transparent to x-rays, except for said registration mark.

In an exemplary embodiment of the invention, the base comprises a radio-opaque grid on at least one of said panels.

In an exemplary embodiment of the invention, the base comprises:

a plurality of pins in at least one of said panels, said pins being adapted to pierce gum tissue but not bone; and at least one encoder which reads a position of at least one of said pins.

In an exemplary embodiment of the invention, said guide attachment point is adapted to hold a block of material.

In an exemplary embodiment of the invention, the base comprises a solid block adapted for engagement by said guide attachment point.

There is also provided in accordance with an exemplary embodiment of the invention, a dental tool guide, comprising:

(a) a base section adapted to be mechanically coupled to hard tissue;

(b) an adjustable guide section having a range of possible orientations in a vicinity of said base section; and

(c) at least one encoder adapted to fit in a human mouth and configured to electronically report an orientation of said guide section relative to said base section. Optionally, said guide section is mechanically coupled to said base section.

In an exemplary embodiment of the invention, said guide section is mechanically de-coupled from said base section.

In an exemplary embodiment of the invention, said guide comprises circuitry which presents at least an indication of said orientation.

In an exemplary embodiment of the invention, said guide comprises circuitry which transmits said report in a wireless manner.

In an exemplary embodiment of the invention, said guide comprises circuitry which transmits said report in a wired manner.

In an exemplary embodiment of the invention, said base is in the form of a surgical stent.

In an exemplary embodiment of the invention, said base is in the form of a brace extending out of said mouth.

In an exemplary embodiment of the invention, said guide section comprises at least one adjustable portion. Optionally, said adjustable portion is adapted to be locked. Optionally, said locking comprises mechanical locking. Alternatively or additionally, said locking comprises locking by application of heat.

In an exemplary embodiment of the invention, said guide is opaque to x-ray radiation.

In an exemplary embodiment of the invention, said guide is transparent to x-ray radiation.

In an exemplary embodiment of the invention, said guide comprises at least one radio-opaque marking.

In an exemplary embodiment of the invention, said encoder comprises an optical encoder.

In an exemplary embodiment of the invention, at least one of said at least one encoder is mounted on said base.

In an exemplary embodiment of the invention, at least one of said at least one encoder is mounted on said guide.

In an exemplary embodiment of the invention, at least one of said at least one encoder comprises at least two sensing parts, a sensed part and a sensing part, each one of said parts mounted on a different one of said guide and said base.

In an exemplary embodiment of the invention, said base is customized to a patient's jaw or teeth.

In an exemplary embodiment of the invention, said base includes a registration mark.

In an exemplary embodiment of the invention, said guide section is in the form of an arm. Optionally, said arm has at least 3 degrees of freedom relative to said base.

In an exemplary embodiment of the invention, said guide section comprises:

a plurality of joints which adjust said drill guide section relative to said base; and

a plurality of encoders which directly measure orientation of said joints. Optionally, said joints are orthogonal to each other.

In an exemplary embodiment of the invention, said guide comprises a drilling depth adjuster.

There is also provided in accordance with an exemplary embodiment of the invention, a dental tool guide aiming-device, comprising:

a base adapted to fixedly engage an adjustable tool guide;

a guide holder adapted to engage a guiding section of said tool guide;

at least one control adapted to move said guide holder and thereby change the orientations of one or more joints of said drill guide. Optionally, said guide holder comprises a peg.

In an exemplary embodiment of the invention, said guide holder prevents translation of said guide.

In an exemplary embodiment of the invention, said control comprises a manual control.

In an exemplary embodiment of the invention, said control comprises a motor.

In an exemplary embodiment of the invention, the device comprises a controlling attachment to a computer. Optionally, said computer includes a display adapted to display an effect of said adjustment.

In an exemplary embodiment of the invention, the device comprises a drill depth adjuster. Optionally, the device comprises a set of replaceable depth adjusters for different depths.

In an exemplary embodiment of the invention, the device comprises a set of sleeves for varying an outer diameter of said peg.

In an exemplary embodiment of the invention, the device comprises a drill length measuring element.

There is also provided in accordance with an exemplary embodiment of the invention, a dental tool guide, comprising:

(a) a base section adapted to be mechanically coupled to hard tissue;

(b) an adjustable guide section having a range of possible orientations in a vicinity of said base section; and

(c) a lock which selectively mechanically locks said guide section to prevent further adjustment. Optionally, said base is in the form of a surgical stent.

In an exemplary embodiment of the invention, said base is in the form of a brace extending out of said mouth.

In an exemplary embodiment of the invention, said guide section comprises at least one adjustable portion.

In an exemplary embodiment of the invention, said locking comprises mechanical locking. Optionally, said locking comprises tightening of a screw.

In an exemplary embodiment of the invention, said locking comprises locking by application of heat.

In an exemplary embodiment of the invention, said guide is opaque to x-ray radiation.

In an exemplary embodiment of the invention, guide is transparent to x-ray radiation.

In an exemplary embodiment of the invention, said guide comprises at least one radio-opaque marking.

In an exemplary embodiment of the invention, said base is customized to patient's jaw or teeth

In an exemplary embodiment of the invention, said base includes a registration mark.

In an exemplary embodiment of the invention, said guide section is in the form of an arm. Optionally, said arm has at least 3 degrees of freedom relative to said base.

In an exemplary embodiment of the invention, said guide section comprises a plurality of joints which adjust said drill guide section relative to said base. Optionally, said joints are orthogonal to each other.

In an exemplary embodiment of the invention, the guide comprises a drilling depth adjuster.

In an exemplary embodiment of the invention, said guide section is permanently attached to said base.

In an exemplary embodiment of the invention, said guide section is selectively attachable to said base.

BRIEF DESCRIPTION OF THE FIGURES

Non-limiting embodiments of the invention will be described with reference to the following description of exemplary embodiments, in conjunction with the figures. The figures are generally not shown to scale and any sizes are only meant to be exemplary and not necessarily limiting. In the figures, identical structures, elements or parts that appear in more than one figure are preferably labeled with a same or similar number in all the figures in which they appear, in which:

Fig. 1 is a schematic illustration of a dental guiding system in accordance with an exemplary embodiment of the invention;

Fig. 2 is a flowchart of a process of dental drill guiding, in accordance with an exemplary embodiment of the invention;

Figs. 3A-3C are schematic views of a dental tool guide, in accordance with an exemplary embodiment of the invention;

Fig. 3D is a schematic showing of a tool guide base with various registration marks, in accordance with an exemplary embodiment of the invention;

Fig. 4A is an schematic external view, and Fig. 4B a cross-sectional schematic view of a tool guide section, in accordance with an exemplary embodiment of the invention;

Fig. 5A is an schematic external view and Fig. 5B a cross-sectional schematic view of a guiding section adjusting device, in accordance with an exemplary embodiment of the invention;

Fig. 6A is a schematic side cross-sectional view of a pin-based dental positioning device, in accordance with an exemplary embodiment of the invention;

Fig. 6B is a blow-apart view of an exemplary implementation of a tool guide, in accordance with an exemplary embodiment of the invention;

Figs. 7A and 7B show a side schematic view and a top schematic view of a side-mounted guide, in accordance with an exemplary embodiment of the invention;

Fig. 8A shows a schematic tool guide having only single wing, in accordance with an exemplary embodiment of the invention;

Fig. 8B shows a denture-based tool guide, in accordance with an exemplary embodiment of the invention;

Fig. 8C shows a brace-based tool guide, in accordance with an exemplary embodiment of the invention;

Fig. 9A shows a schematic smart guide section, in which one or more sensors are included to report on joint positions of the guide, in accordance with an exemplary embodiment of the invention;

Fig. 9B is a cross-sectional view of the guide section of Fig. 9A, in accordance with an exemplary embodiment of the invention;

Fig. 10 shows a schematic tool guide including an x-ray opaque grid, in accordance with an exemplary embodiment of the invention;

Fig. 11 is a schematic showing of a tool guide including a custom bored guide section, in accordance with an exemplary embodiment of the invention;

Figs. 12 and 13 illustrate a contact-less sensing tool guide, in accordance with an exemplary embodiment of the invention; and

Fig. 14 illustrates an alternative contact-less sensing tool guide, in accordance with an exemplary embodiment of the invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

General Overview of System

Fig. 1 is a schematic illustration of a dental guiding system 100 in accordance with an exemplary embodiment of the invention. A dental treatment, for example tooth implantation or prosthesis attachment, is desired at a treatment location/area 104 of a jawbone 102 (lower jaw bone shown for clarity). As will be described below in more detail, a dental tool guide 106 comprising a base section 108 and an adjustable guide section 110 is mounted adjacent location 104. A drill 112 (or other dental tool, for example), is guided by guide section 110. A scanner 114 is optionally used for registration, as described below. A computer 126 or other controller is optionally provided, for example, for planning and/or displaying a path (bore) 122 on a radiological image 124 using an optional display 120, for controlling an optional tool guide adjuster 132, for receiving and/or for sending data using an optional wireless or wired link 128. A user input device, such as a keyboard 130 is optionally provided.

Exemplary Guiding Process

Fig. 2 is a flowchart 200 of a process of dental drill guiding, in accordance with an exemplary embodiment of the invention.

At 202, a patient is diagnosed as requiring some dental treatment, for example, a tooth implantation.

At 204, a radiological image of jaw 102 including treatment area 104 is acquired, for example, a 3D CT image. In some embodiments, this image is not essential, for example, by using a pin array, for example as described in USSN 10/350,288, the disclosure of which is incorporated herein by reference, to acquire a map of the bone surface.

At 206, the location of the implant and/or a suitable bore to be made in the jaw are planned, for example, based on the image. In some cases, several possible bores (or a range of bores) are planned, with the final bore being selected later, for example, during drilling.

At 208, tool guide 106 is attached to jaw 102, typically at or adjacent area 104. In some embodiments, only base section 108 is attached. In an exemplary embodiment of the invention, tool guide 106 is only attached at the vicinity, for example, within a distance of 1-3 teeth form the implant area. In other embodiments, the attachment can be to a greater portion of the jaw, for example, 35%. In an exemplary embodiment of the invention, the gum is not peeled prior to attachment, but in some embodiments it may be. Optionally, base section 108 is attached to a bone. In some embodiments of the invention, base section 108 is adapted to attach to various structures, for example, implants, crowns, teeth and jaws. Optionally, base section 108 includes modular attachment elements, one on either side (e.g., along the line of the jaw), so that section 108 can attach to one structure on one end thereof and to a second structure at a

different end thereof. Such modular attachment elements can be, for example, attached by a snap-fitting or a screw to the body of base section 108.

At 210, part of jaw 102 is scanned, at least including a part of tool guide 106. In one example, guide 106 includes one or more marker or feature which can be identified on the scan and whose position and/or orientation relative to features of the jaw can be determined from the scan. In an exemplary embodiment of the invention, an optical scanner 114 is used for the scanning. Alternatively, a 2D X-ray system is used for the scanning. In an exemplary embodiment of the invention, a further volumetric radiological image, for example x-ray CT, with its associated cost and inconvenience, is avoided.

Optionally, instead of scanning inside the mouth, an impression (e.g., using impression clay) is taken of the mouth while base section 108 is mounted in the mouth. This impression is then scanned outside the body, where it is more accessible.

In an exemplary embodiment of the invention, the scanner used is a line scanner.

In another embodiment an ultrasound imager is used, for example an imager which generates a topographical map of the surface, or an imager which generates an image of the inside of the jaw.

In another embodiment, a contact scanner is used, optionally with a position sensor which allows the position of a contact point of the scanner to be tracked in space.

In another embodiment, an imaging sensor is used for scanning.

In an exemplary embodiment of the invention, the scanned data is used to reconstruct a surface geometry (i.e., topographical map) of at least a part of area 104, including base section 108. Various surface matching and image correlation methods known in the art may used be to combine the acquired data into a surface map and/or for registering the acquired data to the 3D image (below).

Exemplary scanner include: (a) FastSCAN Cobra by Polhemus, described at http://www.polhemus.com/fastscan.htm; (b) Freepoint 3D hand held Sonic Digitizer by GTCO, described at http://www.gtco.com/productfreepoint3d.htm; (c) Pix - 4/30 by Roland DGA: a DESKTOP 3d Active Piezo Sensor scanner, described at http://www.rolanddga.com/products/3D/scanners/pix4_30/default.asp; and (d) A stylus device which can be used to touch landmarks in mouth and on bridge, for example, Microscribe by Immersion, described in http://www.immersion.com/digitizer/.

At 212, a drill type to use and/or an implant to use are optionally selected. Alternatively or additionally, this may be performed earlier, for example as part of optional planning 206, or later, after registration.

At 214, tool guide 106 is registered to the earlier acquired 3D image, for example using the surface scan acquired at 210. In an exemplary embodiment of the invention, one or more registration marks on guide 106 are used to identify the position and/or orientation of guide 106 in the surface map. Alternatively, the outside contour of guide 106 may be used for this purpose. Other registration techniques may be used as well. Once this registration is complete, a display of the image, showing both tool guide 106 and a planned bore may be generated (e.g., bore 122). In some embodiments, planning of drilling trajectory is performed at this point in time.

At 216, guide section 110 is optionally adjusted to fit the planned drilling trajectory. In some embodiments of the invention, an external adjusting tool is used, into which guide section 110 is placed. In other embodiments of the invention, guide section 110 includes one or more sensors which report its position, e.g., via wireless link 128. Optionally, the guide section is manipulated and display 120 shows a resulting bore in real-time. At the end of the adjusting, guide section 110 is optionally locked to have a frozen guiding configuration. Reference 118 is a cross-sectional view of jaw 102 along bore 122, showing bore 122.

At 218, guide section 110 is optionally rigidly attached to base section 108, for example, if it was not so attached before.

At 220, a physician uses tool guide 106 to guide drilling and/or other procedures, such as tissue punching. An exemplary and non-limiting list of tools which may be optionally guided using the methods described herein are: drill guide, soft tissue remover, tool guide, needle, cutter, laser, marking pointer and/or ruler

In an exemplary embodiment of the invention, the display is updated rapidly, for example, faster than once a minute, once a second or even 10 times a second or faster. Such an update rate allows a substantially real time display of the tool position on the display.

In an exemplary embodiment of the invention, guide section 110 is locked. However, in other embodiments, for example if the attachment of base 108 to the jaw is not strong, guide section 110 is left free. In this case, it is the user's responsibility to maintain a correct trajectory. Optionally, the display can be used to guide the user as to the effect and/or as to any deviations from the planned trajectory. Optionally, the tool acts as a user input device to

manipulate the display, for example, by moving the bore and thus a resulting position of the mounted prosthesis.

In an exemplary embodiment of the invention, an effect of the procedure is shown on the display, for example an angle or position of an implant. In an exemplary embodiment of the invention, a complete restoration is planned, for example, one including two tooth implants. A display can show the expected position of the implants and any prosthesis attached to them. Thus, a user can estimate the effect on the final result of the dental restoration, caused by changing a tool trajectory. Optionally, any planned prosthesis is digitally scanned so that it can be displayed and manipulated.

At 222, tool guide 106 is optionally removed from jaw 102.

At 224, some or all of tool guide 106 is optionally disposed of, for example, to ensure sterility, sharpness and/or having a correct spatial configuration. Alternatively or additionally, some or all of tool guide 106 is sterilized and reused.

<u>Two Wing Tool Guide</u>

Figs. 3A-3C shows tool guide 106 in an exemplary two wing implementation thereof. Fig. 3A is an isometric view. Fig. 3B is a side view (along a jaw) and Fig. 3C is a top view (from above a lower jaw).

The general structure shown is two side panels 308 and 310 interconnected by two wings 314 and 316. In an exemplary embodiment of the invention, the wings are positioned so that they do not interfere with dental operations and/or viewing of the treated area.

A guide section 110, described in more detail below, is rigidly attachable to guide 106, for example on top of panel 310. While a variety of attachment mechanisms may be used, in this embodiment, a small base 302 of guide section 110 fits in a recess 301 formed in panel 310 and is locked into position by a movable flap 304 which is pivotally attached to base section 108 by pin-hinges 306. Optionally, flap 304 is elastically urged towards panel 310, to enhance the attachment rigidity.

Optionally, the wings protect guide section 110 from contact of the opposing jaw and/or tools.

In an exemplary embodiment of the invention, wings 314 and 316 provide some degree of elasticity. When mounted on a jaw, if the jaw is wider than the distance between panels 308 and 310, the panels move apart, while being elastically urged towards each other, and the jaw, by the wings. Possibly, different sized tool guides are provided for different locations and/or patient sizes. It should be noted, however, that it may not be necessary to inform the

computerized system of the particular size selected, for example, if the registration point is always at a same location relative to the guide section. In an exemplary embodiment of the invention, the registration point is provided adjacent (and optionally rigidly coupled) the working area, to reduce errors.

Optionally, a plurality of nubs 312 are formed on the panels and provide a better engagement of gum tissue. Alternatively or additionally, one or more of the nubs serves to limit the depth of insertion of the tool guide, by preventing tool guide 106 from being pushed down (or up, in an upper jaw) too far.

Optionally, alternatively or additionally to nubs 312, one or more attachment screws may be provided, for example, a screw 320, which pass through one or both of panels 308 and 310 and can, for example depending on the design, penetrate to the jaw bone or stay on the gum. Alternatively or additionally, one or more clamp elements may be provided.

Fig. 3D is a schematic showing of tool guide base 108 with various registration marks, in accordance with an exemplary embodiment of the invention.

As noted above, in an exemplary embodiment of the invention, optical registration is used to determine a position of tool guide 106 relative to jaw 102. Optionally, an optically visible registration mark 350 is provided in recess 301. Other possible positions for reference marks includes marks 352 and 354 near recess 301 and marks 358 and 356 on the wings. Other reference positions may be provided as well. In an exemplary embodiment of the invention, panel 310 is thin, for example, between 0.5 and 2mm, where it contacts the jaw. In such an embodiment, a registration mark 360 is optionally provided thereon. Optionally, the marks are engraved. Alternatively, the marks are colored in or painted on.

Optionally, one or more holes 330 are provided in tool guide 106, for example in wings 314 and/or 316. In an exemplary embodiment of the invention, holes 330 may be engaged by a suitable tool which spreads apart panels 308 and 310. When released, wings 314 and 316 elastically urge nubs 312 against gum tissue and lock device 300 in place.

Regarding fixation strength. In some embodiments of the invention, the fixation of device 106 to the gum is strong enough to withstand moments and forces typical of drilling. In other embodiments, the fixation is strong enough to prevent inadvertent movement, but cannot withstand strong moments typical of drilling. Optionally, when weaker fixation is used, the tool guide section (described below) is not locked, but is associated with sensors which report its position to a user.

As noted above, other tool guide designs may be used, and several variations are shown below. In some embodiments of the invention, what is desirable about a tool guide is that it be rigidly attachable to a jaw, that a guide section thereof be rigidly coupled to it, and through it to the jaw and that the tool guide be registerable.

Guide Section

Figs. 4A and 4B are a side isometric view and a matching cross-sectional view of guide section 110, in accordance with an exemplary embodiment of the invention.

The general structure shown is a an articulated arm having base 302 at one end and a guide tube 402 at another end, which tube serves as a guide for a drill. Optionally, one or more lumen reducing or modifying inserts 450 are provided in guide tube 402. In the design shown, locking of the guide section to a particular configuration is achieved by rotating a screw 410 so that two opposing side sections of the arm are brought together, increasing friction in all the other joints, which are formed of balls which can rotate in spaces defined between the two opposing side sections.

In the particular embodiment shown, two 2D joints and one 1D joint are provided. In other embodiments, a different number and/or types of joints may be used. Tube 402 is attached to an arm segment 406 by a joint 404 containing a ball 418 (e.g., a ball pivot joint). Arm segment 406 is attached to an arm segment 412 by a plain joint 408, in which screw 410 acts as a hinge and locking element. Arm segment 412 is attached to base 302 by a joint 414 including an internal ball 420. The two side sections of the arm are schematically indicated as references 416 and 422. Screw 410 optionally screws into an element 440 (Fig. 4B).

In an alternative implementation of a locking mechanism, a pair of crescent-shaped stops 444 and 442 are provided (other shapes may be used), each such stop selectively coupling element 440 to balls 418 and 420. Optionally, element 440 is in the shape of a cone, so that as screw 410 is tightened, stops 442 and 44 are pressed outwards from the cone element towards balls 418 and 420.

Optionally, a different locking mechanism is used. In one example, a magnetic locking mechanism is used. In another example, the arm is crimped, to effect locking. In another example, an adhesive drop is applied to the joint(s). In another example, the arm is heated so that a meltable material or a glue flows and locks the joints. Optionally, an electric resistor is provided in the arm (not shown) and is electrified to provide the heat. In an embodiment where an adjuster is used (Fig. 5, below), the adjuster may apply current and/or heat. Similar

mechanisms (e.g., magnetic attraction, adhesive, heat-flowing glue) may be used to attach the arm to base section 108.

Guide 106 may be formed of any dentally acceptable material, for example, titanium, ceramic, stainless steel and/or plastic. Typically, disposable parts will be made of cheaper materials, non-disposable parts will be made of sterilizable materials, and parts which are elastic will be made of metal, however, this is not essential.

Referring back to insert 450, In an exemplary embodiment of the invention, insert 450 includes a handle 452 that extends out of a mouth of the patient and is optionally held by a dentist. This insert may also have one or both of the following functions: protecting guide 402 from the drill and stabilizing the drilling direction.

In an exemplary embodiment of the invention, insert 450 comprises a tube 456 having an inner diameter matched to the drill bit being used. Optionally, tube 456 is coated on the inside with a friction reducing coating. A flange 454 on insert 450 optionally has a thickness which determines a drilling depth.

<u>Guide section Adjuster</u>

Fig. 5A is an outside view and Fig. 5B a cross-sectional views of a guide section adjusting device 500 used to set guide section 110, in accordance with an exemplary embodiment of the invention.

Adjuster 500 works under the following principle, base 302 and guiding tube 402 of guide section 110 are first mounted on adjuster 500 so that each is held in place. Then the relative positions and orientations of base 302 and guiding tube 402 are modified so that if base 302 were attached to base section 108, guiding tube 402 would point along bore 122. Then, guide section 110 is optionally locked and removed from adjuster 500.

In device 500, base 302 is mounted in a base station 502 and guiding tube 402 is mounted on a spindle 504. Base 302 optionally snap-fits to base station 502. Optionally a locking mechanism (not shown) is used. Other connection methods may be alternatively or additionally used as well, for example a magnetic attachment. Spindle 504 includes a bottom stop 506 on which guide tube 402 can rest. Optionally, an upper stop 508 is provided to prevent guide tube 402 from slipping off. Optionally, stop 506 and/or stop 508 can have their axial positions adjusted, for example, by being threaded to spindle 504.

Device 500 comprises two plane control units, 510 and 560, both of which are optionally of similar design and each of which optionally controls the position and orientation of spindle 504 in one of two perpendicular planes which intersect at spindle 504.

Fig. 5B shows a cross-section view of device 500 along the plane controlled by control unit 510. The following discussion focuses on control unit 510, but it should be understood that in this embodiment of the invention, control unit 560 operates in a same manner.

Spindle 504 is held by two X-Y tables 512 and 514. Control unit 510 controls the absolute and relative "X" position of the two tables, thereby setting the spindle position and angle in the "X" plane. Spindle 504 is held in table 512 by a joint 516 and in table 514 by a joint 518. Various types of joints may be used, for example a ball in socket joint for joint 516, or a cylindrical joint. A rod 520 couples control unit 510 to table 512 and a control rod 522 couples control unit 512 to table 514.

Referring to the manipulation of control rod 522 first, control unit 510 comprises a block 524 having a bore 526 in which rod 522 fits. A knob 528 can be rotated to advance rod 522 relative to block 524. Optionally, a threaded rod 530 is provided for rotation by knob 528, which rod 530 abuts and/or is axially coupled to control rod 522.

Referring to the manipulation of control rod 520, a sleeve 538 is fit inside a bore 539 of block 524. A pin 532 (or other means) locks the position of sleeve 538 to that of control rod 522. A slot 534 and a slot 536 are optionally provided for allowing motion of pin 532 with rod 522. Sleeve 538 includes an inner bore 542 in which rod 520 lies and also including a knob 540 and a threaded rod 544 for adjustment of the position of rod 522 relative to the position of sleeve 538.

As noted, tables 512 and 514 can also move in a Y direction, optionally decoupled from "X" direction motion. In an exemplary embodiment of the invention, rods 520 and 522 have a sliding connection to the tables. In the example shown, rod 520 is attached to a block 550 with a bore matching a perpendicular (e.g., in the "Y" direction) rod 552. "Y" direction motion of table 512 will have block 550 slide in a "Y" direction along rod 522, without affecting an "X" direction effect of control unit 510. Table 514 can be coupled to rod 522 by a block 546 with a perpendicular rod 548.

Adjustment along the axis of spindle 504 ("Z" direction") is optional, and may be achieved using movable stops 506 and 508. Optionally, such adjustment is provided to ensure that guide tube 402 will have clearance. Optionally, setting of drilling depth is provided by setting such a "Z" position. Optionally, "Z" setting is provided by placing a fitting on stop 506, to effectively increase its axial thickness. Optionally, a fitting (or one of stops 508 and 508) is used to match an inner diameter of tube 402 to an outer diameter of spindle 502. Alternatively,

even if "Z" position is not modified, knowledge of the "Z" position is used to determine an insert for guiding tube 402 or other means of setting drilling depth.

In a simplest implementation, guiding tube 402 is adjusted by eye, e.g., using knobs 540 etc., until tube 402 is oriented correctly. Optionally, feedback is provided from a display (e.g., on adjuster 500 or display 120, to show the effect of the adjustment).

In another implementation, knobs 540, etc., include markings to show their effect on the layout of tube 402. Optionally, computer 126 is used to generate a set of values for a user to set the knobs to (e.g., based on a table or a calculation that translates a position and orientation to knob settings).

In another implementation, computer 126 directly sets knobs 540, etc., for example using stepper motors (not shown) controlled via a connector (not shown). In a particular implementation, the stepper motors are provided instead of rods 530 and 544. Knobs 528 and 540 may be used for further manual adjustment. Alternatively to stepper motors, linear actuators may be used. Optionally, no controller is provided, alternatively, an internal control may be provided. Optionally, one or more sensors, for example optical encoders (for example on the rods) are provided for reporting on the relative and/or absolute positions of parts of adjuster 500. Optionally, a user may still manipulate tube 402, for example to prevent the computer controlled stepper motors from bending the guiding section in a manner for which it was not designed or to try out variations. One reason for manual adjustment of tube 02 and/or the knobs is to allow a user to make changes, for example to provide a more esthetic implantation location or angle or a location better optimized for improved restoration.

In another implementation, the guiding section may include one or more sensors that report on its joint positions. The reported values may be used, for example for displaying feedback or for feeding a computer controlled feedback loop used for controlling the tube adjustment. Alternatively or additionally, such sensors may be provided in adjuster 500, and may for example provide feedback only on device 500 (e.g., if it includes a display), or may be provided to computer 126.

It should be appreciated that the illustrated adjuster 500 is just one type of adjuster that can be used. In general, many hexapod designs are known, many of which may be modified for use with the present invention (e.g., modified to hold the guiding section)

In an alternative adjuster design, guiding section 110 is placed inside an outer sleeve and the outer sleeve is manipulated to adjust each joint of section 110 separately.

Optionally, adjuster 500 is attached or adapted to be attached (e.g., size and/or magnetic attraction) to a dental tool tray.

Optionally, adjuster 500 includes a ruler for measuring the length of the drill burr. In an exemplary embodiment of the invention, a plain ruler is marked and a user enters the result using user input 130. Alternatively, the resulting length may be used to choose a matching drill length insert 450.

In an alternative embodiment of the invention, a spring-based ruler is used. In one example, a bore 572 is formed in adjuster 500. When a drill burr is inserted through an aperture 570 thereof, it presses against a spring 574. A marker 576 can indicate the length on a suitable graded window.

In an exemplary embodiment of the invention, a pressure sensor 578 senses the tension in the spring an generates a signal indicative of the length. Other measuring methods may be used as well.

As noted above, in some embodiments of the invention, adjuster 500 applies heat, for example to melt glue in arm 110. In an exemplary embodiment of the invention, heat is applied at spindle 504 and base station 502. Such heat is optionally conducted by metal parts of arm 110 (if a metal arm is used). Alternatively, a heat lamp may be used. In an exemplary embodiment of the invention, arm 110 is formed of a strip of heat-trainable material, such as a shape memory material or a heat-softened plastic, which, once heated above a training temperature, retains that shape, and which interconnects base 302 and guide 402 (or serves as a joint). In use, adjuster 500 is used to distort the strip. Optionally, the strip is made thinner at the attachment to base 302 and tube 402. Then, heat is applied to train the arm to its new configuration.

In another embodiment, a goose-neck arm (such as used in goose-neck lamps, but smaller) is used and adhesive is flowed between the chinks of the goose-neck to lock the arm in a certain configuration.

Self mapping guide

Fig. 6A is an isometric view of a pin-based dental positioning device 600, in accordance with an exemplary embodiment of the invention. This implementation is described in more detail in USSN 10/350,288. In general, two panels 602 and 604 each include a plurality of pins 606. In an exemplary embodiment of the invention, each panel includes a two dimensional array of pins. When pressed against hard tissue, the relative positions of the pins indicate a topography of the hard tissue surface. In an exemplary embodiment of the invention,

the pins have associated with each one an optical encoder 620 which reads a pin position and/or movement from lines 622 engraved on the pin. Other read-out methods are possible. In an alternative implementation, the pins are locked in place and then the panel removed and read outside the body. Optionally, the pins are arranged in modules which can be removed without detaching device 600 from the jaw. Then, a tool may be provided through a side panel to a desired location on the hard tissue. A tool guide section is optionally mounted on a bridge 605 between the two panels. Optionally, one or both of panels 602 and 604 can be moved linearly (e.g., on a rail or along a screw) along bridge 605 towards the other panel. In the implementation shown, an air inlet 614 is used to provide pneumatic pressure to advance pins 606 through gum tissue and to a bone. Not described are elements 607, 616, 610, 618, 612 and 609 described in the above mentioned US patent application.

In an exemplary embodiment of the invention, pins 606 are used to acquire a surface image of the jawbone instead of using a CT image.

In an alternative implementation, the pins give a bone surface image which can be correlated or otherwise matched to a CT image, so that a surface scanning is not required.

In another embodiment, a surface map acquired by pins is combined with an x-ray image showing a mandibular canal on the background of device, 600, giving a more or less complete information useful for making dental decision.

While any of the guide sections described herein may be used, In an exemplary embodiment of the invention, the guide section comprises a hollow ball joint that is mounted on bridge 605, for example, if bridge 605 is a tube with an aperture at its top. The ball can be rotated in one, two or three degrees of orientation freedom, depending on the implementation. Optionally, linear motion along the bridge is also allowed.

Optionally, one or more optical encoders are provided in the bridge, for example to read position markings off of the ball and indicate its orientation and/or position.

In an alternative implementation, the ball is replaced by a tube axially positioned in the bridge tube (and which supports rotation and/or axial motion) and a cylindrical joint which rotates in a direction of the axis of the bridge tube. Fig. 6B shows an exemplary such implementation. The reference numbers are described in the above referenced US application by the applicant.

It should be noted that pins 606 can be used for surface mapping also for other applications, in one example, pins 606 are used to track bone loss. In another, the pins are used to track the effect of bone enhancement (e.g., by periodic checking). Optionally, a panel is also

provided on the top of the implant. For correlation purposes, possibly a single panel can suffice.

Side mounted guide

Figs. 7A and 7B show a side schematic view and a top schematic view of a side-mounted guide 706, in accordance with an exemplary embodiment of the invention. In this design, a base section 708 is mounted to a tooth 701 adjacent the treatment area. A guiding section, for example section 110 described above, is mounted on an extension 726 of base section 708, so that a base portion 302 of section 110 is at approximately a same position relative to the treatment area as in device 106.

Base section 708 includes a ring section 720 adapted to hold tooth 701. For example, ring section 720 may comprise two band parts 721 and 722 which can be attached by a lock 724, which optionally applies tension and/or selectively shortens ring section 720. Many band (or other) mechanisms for holding teeth are known in the art and may be used. Optionally, ring section 720 is thin enough, at least at some parts thereof, so it can fit between two teeth.

In an alternative implementation, ring section 720 is elastic and can be held open to be placed around the tooth and then released to close and lock tightly to the tooth. To this end, a hole is optionally provided in each of band parts 721 and 722, to serve as a force application point for a pliers like tool that opens ring section 720.

Base plate 302 of guiding section 110 is optionally mounted in a depression 704, for example, as provided for in Fig. 3.

It should be noted that the length of extension 726 (i.e., offset from tooth 701) maybe varied for various implanting situations.

One potential advantage of the guide 706 is that there are fewer elements in the mouth which might block a view or access to the implant area.

Single wing guide and other guide variations

Fig. 8A shows a tool guide 806 similar to guide 106, except that only single wing 316 is provided. This may reduce interference with view and/or access to the treatment area.

Fig. 8B shows a denture-based tool guide 810, in accordance with an exemplary embodiment of the invention. In this implementation, a denture like base section 812 is provided. this has the potential advantage of being fixed to a relatively large portion of a jaw, for example, 35% or more, so that a single reference frame can be used for multiple treatments. In the example shown, a wide work aperture 816 is provided. One or more tool guide sections (not shown) optionally mount on one or more rails 814. Optionally, the tool guide(s) can be

moved along the rails, for example from one position to a next position. Alternatively or additionally, multiple tool guides are used together, for example to setup simultaneous bores for two implant locations.

Fig. 8C shows a brace-based tool guide 830, in accordance with an exemplary embodiment of the invention. A brace mounting allows the tool guide to be coupled to bone not at the treatment area. In the example, shown, a rail 832 contacts a lower jaw at a rest 834, for example, a padded fork. An inner jaw extension 840 optionally engages the front of the jaw, from the inside. An extension 836 optionally contacts the bottom of the jaw, at a padded contact 838. A knob 842 is optionally provided for controlling the length of rail 832. Typically, a pair of such extensions and contacts is used, so that both sides of the jaw are engaged at once. Other designs may be provided.

A tool guide is optionally mounted on rail 832 or on another part of brace guide 830.

Other types of bases and attachment methods may be used as well. In one example, the base has a layer of dental impression material (such as Impregum). In another example, one or more suction cups or adhesive areas are used to provide attachment. In another example, base section 108 is adapted to attach to an implant or to a temporary splint. In another example, base 108 is a stent, for example formed by impression or other methods known in the art, and including an attachment area.

For example, stent 106 can be a mass-produced item or a customized item. For example, a customized brace or a customized stent may be used. Alternatively, one or more standard sizes of stents are provided (e.g., standard gap widths and standard heights, for a dentist to select from.

Smart guide

Fig. 9A shows a smart guide section 910, in which one or more sensors are included to report on joint positions of the guide, in accordance with an exemplary embodiment of the invention. Such sensors can be incorporated in guide section 110, however, it should be noted that guide section 910 also illustrates a simpler design, with fewer degrees of freedom. Fewer degrees of freedom may allow the use of fewer sensors and possibly lower cost.

In the embodiment shown, four degrees of freedom are provided:

(a) a guiding tube 902 can be pivoted around a Y axis at a tilt joint 920;

(b) tube 902 along with joint 920 can further be moved along an X axis or rotated around the X axis at a joint 930; and

(c) joint 930 can be translated along a Y axis at a sliding joint 940.

The design shown is tube 902 mounted on a rod 926, which rod is movable in a box 928 having a tail section 934 and a bottom section 936. In an exemplary embodiment of the invention, the one or more of the following sensors are provided:

(a) a tilt sensor 922 reads a tilt of tube 902 relative to a pin 924 which couples tube 902 to rod 926;

(b) an extension sensor 932 which measures an extension of rod 926 relative to box 928;

(c) a rotation sensor 938 which measures a rotation of rod 926 around its axis; and

(d) a translation sensor 942 which measures translation of bottom section 936 along joint 940, relative to a separate base portion 950 with one or more rails 952.

The sensors can be, for example one or more of optical sensors, magnetic sensors, capacitance sensors, piezoelectric sensors and potentiometers. Various translation and rotation methods and devices may be used as well, for example, linear and rotational encoders or imaging detectors.

A potential disadvantage of guiding section 906 is that it is flat and cannot bypass obstacles. Optionally, the base section used is positioned so that depression 304 is at a plane or above a plane of tissue at the implant area.

In operation, tilting and rotation of tube 902 set the orientation of the bore of a drill. Translation of rod 926 and box 928 set the position of one point along the bore. Optionally, the electronics for the sensors is in tail section 934. Optionally, tail section 934 also includes a wired or wireless transmitter. Alternatively, tail section 934 includes an indication of correct positioning, for example a LED which lights when a current position and/or orientation of tube 902 does not match a planned trajectory. For example, tail section 934 may include a wired or wireless receiver, or contacts for programming a desired orientation, and one or more LEDs or other light sources on section 906 change their illumination if the sensors are within a tolerance of their correct orientation. Alternatively or additionally, computer 126 may attend to reporting the position, for example as bore marking on display 120, or using an audio display.

In an exemplary embodiment of the invention, the sensors used are optical encoders reading on optical encoding off of a part of the joint. Many types of optical encoders which are suitable are known, for example, fiber optic sensors with control electronics in tail section 934 may be used. Alternatively, other, relative or absolute sensors may be used. Optionally, box 928 serves to protect some or all of the sensors from the environment.

Fig. 9B is a cross-sectional view of guide section 910, showing locking and encoding details. In particular, a plurality of line engraving reference areas 923 939 and 933 are shown respectively for sensors 924, 938 and 932. Optionally, a rail 964 has marking 943 thereon for sensor 942. In an exemplary embodiment of the invention, rail 964 (optional two are provided) is designed to rigidly engages bases section 108.

An exemplary and optional locking mechanism is shown as well. When a knob 980 is rotated, a threaded inner rod 962 is pulled back, urging pin 924 towards knob 980. This increases friction in guide section 910, locking it in place. Rotational and axial locking is optionally provided by a screw (not shown) which selectively engages rod 926 when rotated and is inserted, for example, through the top of box 928 and perpendicular to rod 926.

Contact-less position sensor based guiding

In the embodiments described above, sensors are provided in the arm that moves. In alternative embodiments of the invention, contact-less sensors are used. In an exemplary embodiment of the invention, one sensor portion is provided on a base section and another on the part whose position relative to the base needs to be determined.

Figs. 12 and 13 illustrate a contact-less sensing tool guide, in accordance with an exemplary embodiment of the invention.

Fig. 12 shows a sensor 1202 mounted on a stylus 1214. A panel 1206 with markings 1208 is provided on the base section, for example on a wing thereof, so that the signals generated by sensor 1202 relate to the relative position and/or orientation of sensor 1202 and panel 1206. Various sensor types may be used, for example, sensor 1202 may be an imaging sensor. In another embodiment, sensor 1202 is a linear or scalar optical detector. Relative and absolute sensors may be used. If a relative sensor is used (e.g., one which detects motion), a zeroing step of moving the sensor to a known "zero" position may be used to prevent accumulation of errors. Optionally, sensor 1202 includes an illumination for panel 1206. In an alternative embodiment, panel 1206 is self illuminated. Alternatively, external or no illumination is provided.

Other types of sensors may be used, for example, magnetic sensors or ultrasonic time of flight sensors. While generally not desirable as it may reduce accuracy and be cumbersome, in an exemplary embodiment of the invention, a magnetic field sensors is used which measures an externally applied (e.g., from outside of the mouth) magnetic field.

Optionally, a second (or more) sensors 1204 with a matching panel 1210 and markings 1212, is provided.

Optionally, an inclination sensors 1214 is provided on the base section and a second inclination sensor 1216 is provided on stylus 1214, so that their relative inclinations may be determined. It should be noted that for implant boring, the range of angles is generally not very great, due to mechanical constraints of the jaw.

Fig. 13 shows stylus 1214 mounted in a tool guide section 110 as described above, and which can be used to generate position .information while guide section 110 is being manipulated by stylus 1214. Optionally, this allows the stylus to be used as a user input to control display 120. In an alternative embodiment, sensors 1202 and 1204 are mounted on tube 402 of guide section 110. Alternatively, the sensors are mounted on a drill handle or a handle for other dental tools.

Contact-less sensors may be used in various configurations. In a first set of configurations, a guide arm 110 (or the like is provided). If arm 110 is lockable, contacts-less sensors can be operated much as other sensors. In an exemplary embodiment of the invention, however, stylus 1214 is used to manipulate arm 110 and once a correct positional and angular configuration is achieved, guide arm 110 is locked, for example, using an electric current to melt glue therein. This may be achieved, for example, under computer control and optionally using a power source wholly included in the tool guide, such as a battery. Optionally, this allows arm 110 to be permanently fixed to the base section. It should be noted that in such an application, longer sensor integration times may be allowed, as real-time updating of display 120 may be less important. If guide arm 110 is not lockable, sensors 1202 and 1204 may be used to provide real-time updating of the position of arm 110 in space, as described above. It should be noted that arm 110 can be made cheaper, as it can be made with no sensors.

In a second set of configurations, no guide arm, per se, is provided. instead, sensors 1202 and 1204 are used to detect a position and/or orientation in space of stylus 1214 (or a tool or a sleeve adapted to be mounted on a tool) relative to the base section.

Fig. 14 illustrates an alternative contact-less sensing tool guide 1400, in accordance with an exemplary embodiment of the invention. In this embodiment, sensors 1402 and 1404 are mounted on a base section 1409 of guide 1400, and panels 1406 and 1408 are provided on tool guide section 110. As shown in this embodiment, the markings can, for example, be two dimensional, so that each sensor might provide 2 or 3 dimensions of information. Panels such as panels 1406 and 1408 may also be provided on a sleeve, as stickers, on a drill, on a dental tool or on a tool holder. As described above, inclination sensors are optionally provided. As described above, illumination is optionally provided.

While the sensors are optionally provided calibrated to the markings, optionally a calibration procedure can be used, for example, contacting stylus 1214 to one or more pre-defined points on the stent. Optionally, a form is provided that fits in the stents, so that an orientation of stylus 1214 can also be controlled, for example, as shown in Fig. 11, but not blocking the field of view of the sensors.

Similarly to guide section 108, contact-less sensors may be used in adjuster 500, to report on the position of guide tube 402. Optionally, adjuster 500 will include in such a case only a heating element for fixing guide arm 110 in place, rather than the knob and x-y table arrangement described.

<u>X-ray registration guide</u>

In an exemplary embodiment of the invention, 2D x-ray transmission images are used for registering the tool guide to a known jaw geometry (e.g., a geometry provided by a CT image). Fig. 10 shows a tool guide 1006 including an x-ray opaque grid 1008, in accordance with an exemplary embodiment of the invention. The rest of guide 1006 can be transparent to x-ray, for example being made of plastic, and optionally transparent to light, at least in some parts thereof. The grid can be, for example, lines of a known length and/or one or more crosses.

In use, two linear grids are provided on either side of the jaw (e.g., grid 1008 and a grid 1014, not visible), and an image is acquired through the jaw and the tool guide, for example using a reusable or non-reusable x-ray plate 1010. Plate 1010 is optionally attached to one side of guide 1006, for example using an attaching and/or aligning element 1016. Optionally, guide 1006 includes an x-ray plate holder. Optionally, an external aiming element is attached or attachable to guide 1006, and includes an extension out of a mouth and including a ring or other target at its end for aiming an x-ray tube. In the resulting images, the grids show the layout of guide 1006 relative to the jaw structures, in a certain projection direction. The relationship between the two grids indicates the direction.

In an alternative embodiment of the invention, one of the opaque grids, for example a grid 1012 is provided on plate 1010.

In an alternative use, such a grid is used instead of one or more CT images. For example, such a grid can indicate a relative depth to a mandibular canal.

If a pin based device as shown in Fig. 6 is used, a complete data set may be obtained. The pins provide a surface image and the x-ray grid shows an allowed depth (to the mandibular

canal). This data is good enough to generate a cross-section view of area 104, in which the possibilities of drilling a bore are shown.

Alternatively to plain x-ray images, more complex images, such as panoramic, and periapical x-ray images may be used. Optionally, the grids are used as an aiming tool, in which a user can pierce plate 1010 to reach the desired treatment area through the body of guide 1006. Guide 1006 may have a soft section or an aperture or a removable cover (e.g., removing pin modules from the embodiment of fig. 6) to prevent damage and/or dislodgment of guide 1006.

Fabricated guide

Fig. 11 shows a tool guide 1100, having a custom fabricated guide section 1104 adapted to mount on a standard base section 1102, in accordance with an exemplary embodiment of the invention.

In the example shown, guide section 1104 comprises a block of material in which a bore 1108 has been drilled, to achieve a desired drilling direction. In an exemplary embodiment of the invention, an insert 450 is provided, for example, to prevent damage to guide section 1104 by a drill burr 1110 and/or to adapt its diameter and/or a drilling depth.

In the embodiment shown, one or more spring clamps 1106 is used to hold guide section 1104 in place.

In an exemplary embodiment of the invention, guide section 1104 is fabricated in the following manner. A block of solid material, such as plastic, is placed on an X-Y table and is moved relative to a drill, for example, under manual or computer control. The drill is then powered and advanced to drill through the block, for example using a drill-press. Optionally, the drill is mounted on gimbals to control its orientation. Alternatively, the X-Y table is so mounted. In one example, a hexapod structure, of which many are known in the art for three dimensional positioning, is used. Other positioning and orientating methods described herein or known in the art may be used instead of an X-Y table, for example, an articulated arm. In one example, a positioning system as described herein is used to control or display the position and orientation of a dental drill of a large bore, which drill is used for drill 1110.

It will be appreciated that the above described methods of bone surface measurement and tool guiding may be varied in many ways, including, changing the order of steps and the types of tools used. In addition, a multiplicity of various features, both of method and of devices have been described. In some embodiments mainly methods are described, however, also apparatus adapted for performing the methods are considered to be within the scope of the

invention. It should be appreciated that different features may be combined in different ways. In particular, not all the features shown above in a particular embodiment are necessary in every similar embodiment of the invention. Further, combinations of the above features are also considered to be within the scope of some embodiments of the invention. Also within the scope of the invention are surgical kits which include sets of medical devices suitable for performing a single or a small number of measurements, tool guiding and/or implantation. Also, within the scope is hardware, software and computer readable-media including such software which is used for carrying out and/or guiding the steps described herein, such as surface matching and bore selection. Section headings are provided for assistance in navigation and should not be considered as necessarily limiting the contents of the section. When used in the following claims, the terms "comprises", "includes", "have " and their conjugates mean "including but not limited to".

It will be appreciated by a person skilled in the art that the present invention is not limited by what has thus far been described. Rather, the scope of the present invention is limited only by the following claims.